S. Residual Solids Management

This chapter deals with the treatment of residual solids (biosolids and sludge) from wastewater treatment plants, including information on solids concentration, stabilization, composting, and storage. Limited information is also included on the potential options for recycling and disposal of residual solids. The terms “biosolids,” “sludge,” and “residual solids” are clarified in S-1.1 and used throughout this chapter.

Tables

S-1 General

S-1.1 Biosolids, Sludge, and Residual Solids Definitions

"**Biosolids**" and "**sludge**" are terms defined differently in statutes, rules, and guidelines. The Water Environment Federation (WEF) was first to adopt a formal definition of biosolids, and Washington State was arguably the first state to use it in a statute (Chapter 70.95J RCW). The definitions found in various sources may appear similar, but there are often differences reflecting the needs of the particular application.

"**Residual solids**" describes a broad range of materials that might be encountered in the management of a sewage treatment plant, including biosolids and sludges in general. Definitions used in the regulatory context of Washington State law and wastewater discharge permits are provided in the following subsections.

S-1.1.1 Biosolids

Biosolids is defined in RCW 70.95J.010(1) as municipal sewage sludge that is a primarily organic, semisolid product resulting from the wastewater treatment process that can be beneficially recycled and meets all applicable requirements of Chapter 70.95J RCW. The term biosolids includes materials derived from biosolids (such as compost) and septic tank sludge (also known as septage) that can be beneficially recycled and meets all applicable requirements of Chapter 70.95J RCW.

S-1.1.2 Sludge

Sewage sludge is defined in RCW 70.95J.010(4) as a semisolid substance consisting of settled sewage solids combined with varying amounts of water and dissolved materials, generated from a wastewater treatment system, that does not meet the requirements of Chapter 70.95J RCW.

Chapter 70.95J RCW is the enabling statute for Washington State's biosolids rule, Chapter 173-308 WAC. The significance of the reference is that sewage sludge that meets the standards of the biosolids rule is not considered solid waste. Sewage sludge not meeting standards in Chapter 173-308 WAC is solid waste and cannot be applied to land.

S-1.1.3 Residual Solids

Residual solids includes screenings, grit, scum, primary sludge, waste activated sludge, and other solid waste.

S-1.2 Regulations

This subsection provides a brief explanation of federal and state requirements, which primarily consist of 40 CFR Part 503 and Chapter 173-308 WAC.

S-1.2.1 Federal

40 CFR Part 503 contains the requirements for land application of biosolids. Biosolids are designated as either Class A or Class B with regard to pathogen density and vector-attraction reduction. For Class A biosolids, the pathogen reduction requirements must be met before or at the same time as most of the vector-attraction reduction requirements. To produce Class A biosolids, one of six alternative processes must be used. Enhanced digestion processes such as

thermophilic anaerobic digestion, dual digestion, and autothermal aerobic digestion can produce Class A biosolids by qualifying under one of the 40 CFR Part 503 alternatives for meeting Class A pathogen requirements.

Compliance with 40 CFR Part 503 is required. The US EPA is presently responsible for enforcing the provisions of 40 CFR Part 503. Treatment works treating domestic sewage that have NPDES permits are required to submit complete permit applications to EPA for the final use or disposal of sewage sludge produced. Other treatment works treating domestic sewage (such as sewage treatment plants with state waste discharge permits) are required to submit Part 1 of the federal permit application to EPA.

S-1.2.2 State

A state rule on biosolids management (Chapter 173-308 WAC) was adopted by Ecology and became effective on March 21, 1998. The rule establishes standards, management practices, permitting requirements, and permit fee schedules for facilities that store, treat, and recycle municipal or domestic sewage sludge or biosolids, as well as any sites where the biosolids are land-applied. In this rule, standards that pertain to pathogen reduction and vector-attraction reduction correspond to those set forth in the 40 CFR Part 503 regulations.

Sewage sludge which is disposed in a municipal solid waste landfill must not be a hazardous waste and must pass the paint filter liquids test (free liquids ban). The dewatering requirement is often difficult for operators to meet. WAC 173-351-220(10) identifies additional restrictions and requirements for disposing of sewage sludge in a municipal solid waste landfill. Ecology's preference is recycling (Chapter 70.95 RCW and Chapter 70.95J RCW). Those facilities wishing to dispose of biosolids in a municipal solid waste landfill on an emergency or short-term basis are required to obtain determinations of need and permission from local health departments. Those wishing to do so on a long-term basis may need to demonstrate the economic unfeasibility of other options to Ecology.

Ecology has used draft guidelines, "Biosolids Management Guidelines for Washington State, 93-80," as a working document since 1993. These guidelines attempt to bridge the gap between the state's past program and the newer requirements in 40 CFR Part 503 and Chapter 173-308 WAC. Ecology has been encouraging local health departments and operators to use the draft guidelines (with some caution for errors contained therein), until a final version is released. These draft guidelines are being revised in 1998 and final guidelines are expected to be released early in 1999 (as of this printing).

S-2 Solids Treatment

Treatment of solids generally involves reduction in water content and stabilization of the sludge.

S-2.1 Solids Concentration

The purpose of solids concentration is to increase the solids content of the sludge by reducing the water in the sludge.

Methods of solids concentration include:

- Gravity thickening/settling.
- Dissolved air floatation.
- Gravity belt filtration.
- Belt filter press.
- Centrifuges.
- Drying beds.
- Thermal drying.
- Bag dewatering/air drying.

S-2.1.1 Gravity Thickening/Settling

Gravity thickening is one of the lower-cost operation and maintenance methods of thickening primary or secondary solids. It is also the simplest of the thickening options available.

A. Purpose

The purpose of thickening is to lower the liquid content of the residual solids, thus reducing equipment capacity needs. An example would be thickening settled solids from a secondary clarifier from 1-percent to 3-percent solids using a gravity thickener. Reducing the liquid content of the solids from 1-percent to 3-percent solids effectively reduces the volume of the product to one-third of its original volume. Therefore, storage and blending tanks, as well as pumping and piping capacity, could be sized one-third smaller as compared to similar equipment for solids with a 1-percent concentration.

B. Design Considerations

Gravity thickeners are typically circular in shape and function identically to clarifiers (refer to Chapter T2). The use of rectangular tanks is not as common as circular tanks; however, rectangular tanks are far more space-efficient as compared to circular tanks of the same capacity rating.

A rough design guideline is presented in Table S-1 when test data are not available and pilot plant tests are not practical.

Table S-1. Rough Design Guidelines to Determine Solids Mass Loading

Solids Source	Incoming Solids Concentration (percent solids)	Expected Product Concentration (percent solids)	Mass Loading (lbs/sq-ft/hr)
Primary (PRI)	2 - 7	5 - 10	0.8 - 1.2
Trickling Filter (TRI)	1 - 4	3 - 6	0.3 - 0.4
Rotating Biological Contactor (RBC)	1 - 3.5	2 - 5	0.3 - 0.4
Waste Activated Sludge (WAS)			
Air	0.5 - 1.5	2 - 3	0.1 - 0.3
Oxygen	0.5 - 1.5	2 - 3	0.1 - 0.3
Extended aeration	0.2 - 1.0	2 - 3	0.2 - 0.3
Aerobically Digested Solids from Primary Digester	8	12	1.0
Thermally Conditioned Solids			
PRI only	3 - 6	12 - 15	0.6 - 2.1
PRI + WAS	3 - 6	8 - 15	1.2 - 1.8
WAS only	0.5 - 1.5	6 - 10	0.9 - 1.2
Tertiary Solids			
High Lime	3 - 4.5	12 - 15	1.0 - 2.5
Low Lime	3 - 4.5	10 - 12	0.4 - 1.25
Iron	0.5 - 1.5	3 - 4	0.1 - 0.4
Other Solids			
PRI + WAS	0.5 - 4.0	4 - 7	0.2 - 0.7
PRI + TF	2 - 6	5 - 9	0.5 - 0.8
PRI + RBC	2 - 6	5 - 8	0.4 - 0.7
PRI + iron	2	4	0.25
PRI + low lime	5	7	0.8
PRI + high lime	7.5	12	1.0
PRI + (WAS + iron)	1.5	3	0.25
PRI + (WAS + alum)	0.2 - 0.4	4.5 - 6.5	0.5 - 0.7
(PRI + iron) + TF	0.4 - 0.6	6.5 - 8.5	0.6 - 0.8
(PRI + iron) + WAS	1.8	3.6	0.25
WAS + TF	0.5 - 2.5	2 - 4	0.1 - 0.3
Aerobically digested (PRI + WAS)	4	8	0.6
Aerobically digested PRI + (WAS + iron)	4	6	0.6

1. Hydraulic Loading

Hydraulic loading is related to mass loading and controls the amount of solids carryover into the supernate. The quantity of solids entering the thickener is equal to the product of the flow rate and solids concentration. Since there are definite upper limits for mass loading, there will therefore be some upper limit for hydraulic loading.

Typical maximum hydraulic loading rates of 25 to 33 gsfh have been used successfully with primary solids. For solids from activated sludge and similar processes, much lower hydraulic loading rates, 4 to 8 gsfh, are more applicable. Using the typical maximum hydraulic loading rates mentioned produces maximum upward tank velocities of 3.3 to 4.4 fph for primary solids, and 0.5 to 1.0 fph for activated sludge solids.

2. Total Tank Depth

The total vertical depth of a gravity thickener is based on three considerations: tank free board, settling zone (zone of clear liquid and sedimentation zone), and compression and storage zone (thickening zone).

a. Free Board

Tank free board is the vertical distance between the tank liquid surface and the top of the vertical tank wall. It is usually set at a minimum of 2 to 3 feet.

b. Settling Zone

This zone encompasses the theoretical zone of clear liquid and sedimentation zone (just above the thickening zone). Typically 4 to 6 feet is necessary, with the larger measurement used for more difficult solids from activated sludge processes or nitrification processes.

c. Compression and Storage Zone

Sufficient tank volume must be provided so that the solids will be retained for the period of time required to thicken the slurry to the desired concentration. Additionally, sufficient storage is necessary to account for fluctuations in the solids loading rate.

3. Circular Tanks—Drive Torque

Thickened solids on the floor of a circular tank resist the movement of the solids rake and thus produce torque. The torque for different types of solids varies from 20 to up to 80 lb/ft.

4. Compression and Storage Zone

Gas may be produced from anaerobic conditions or denitrification. These conditions are dependent on the type of solids, liquid temperature, and length of time the solids are kept in the thickener. A general guideline based on operational data recommends that the total volume in this zone not exceed 24 hours of maximum solids wasting.

5. Circular Thickener—Floor Slope

The floor slopes of circular thickeners are normally more than 2 inches of vertical distance per foot of tank radius. This is steeper than the floor slope for standard clarifiers. The steeper slope maximizes the depth of solids over the solids hopper, allowing the thickest solids to be moved. The steeper slope also reduces solids raking problems by allowing gravity to do a greater part of the work in moving the settled solids to the center of the thickener.

6. Skimmers

Skimmers are recommended for thickeners that process solids from secondary biological wastewater treatment processes. The skimmers remove the floating scum layer associated with solids from such treatment processes.

7. Polymer Addition

The addition of polymers for gravity thickening improves solids capture but has little or no effect on increasing the solids concentration of the thickened product.

8. Thickener Underflow Pump and Piping

For variable head conditions and abrasiveness typical of many types of solids, a positive displacement pump with variable speed drive should be used. Its operation could be set manually, or controlled by some type of solids sensor. A positive or pressure head should be provided on the suction side of the pump. A minimum head of 10 feet should be provided for primary solids, and a minimum head of 6 feet for all other solids. It is critical to provide adequate cleanout and flushing connections on both the pressure and suction sides of the pump. Cleanouts should be brought to an elevation greater than that of the liquid surface of the thickener to allow cleaning without emptying the thickener.

9. Rectangular Tanks

Flow distribution in rectangular tanks is critical. Possible approaches to inlet design are as follows:

- Full width inlet channels with inlet weirs.
- Inlet channels with submerged ports or orifices.
- Inlet channels with wide gates and slotted baffles.

Inlet weirs, although effective in spreading flows across the tank width, introduce a vertical velocity component into the solids hopper that may resuspend the solids. Inlet ports can provide good distribution across the tank width if the velocities are maintained in the 10- to 30-foot minimum range. Inlet baffles are effective in reducing the high initial velocities and distribute flow over the widest possible cross-sectional area. Where full-width baffles are used, they should extend from 6 inches below the surface to 12 inches below the entrance opening.

S-2.1.2 Dissolved Air Floatation

A. Purpose

Dissolved air floatation (DAF) thickeners can be utilized either to thicken wastewater solids prior to dewatering or stabilization or to thicken aerobically digested or other solids prior to disposal or dewatering.

B. General Description

In the DAF thickening process, air is added at pressures in excess of atmospheric pressure, usually to a liquid stream separate from the residual solids stream. The two streams are then mixed at atmospheric pressure, and the resultant pressure change for the liquid stream causes the release of very fine bubbles in the mixed stream. The bubbles adhere to the suspended particles or become enmeshed in the residual solids matrix. Since the average density of the solids-air aggregate is less than that of water, the product floats to the surface. The floating solids build to a depth of several inches at the water surface. Water drains from the float, and affects solids concentration. Float is continuously removed by skimmers.

With the use of polymers, most DAFs operate at a design capacity of 2 pounds of solids per square foot of skimming area per hour. The expected thickened solids concentration from typical systems using polymers is normally 5 to 6 percent solids. However, there is no substitute for obtaining empirical data from bench-scale or pilot-scale tests.

C. Requirements

At a minimum, bench-scale tests performed to evaluate the system are recommended. Leasing a unit that is representative of the recommended system for pilot testing would be ideal, and should give a more realistic evaluation of design considerations and operating parameters.

D. Design Considerations

1. Pressure System

- DAF for solids thickening applications should always use tank effluent pressurization. Feed solids pressurization could result in excessive wear in feed solids pumping systems.
- Float will contain numerous air bubbles that can cause air binding in thickened solids pumping systems downstream of a DAF. A solids equalization tank with 6 to 12 hours of thickened solids capacity should be provided downstream of the float beach to permit offgassing of the bubbles. This equalization tank should be completely enclosed and ventilated to an appropriate odor control system.
- Sufficient effluent recirculation and pressure tank pressure should be provided to produce a minimum air-to-solids ratio of 3 percent under all operating conditions.
- The basic mechanism that makes floatation possible is the increase in the amount of gas dissolved when pressure is increased. Depending on the design of the pressure equipment, efficiencies can range from 50 to 90 percent. It is desirable to maintain the efficiency of the pressure system in a range of 80 to 90 percent.

2. Costs and System Selection

A cost comparison between DAF and gravity belt thickening should be performed. Gravity belt thickeners are usually lower in cost, have a smaller footprint, and achieve a higher thickened solids concentration than DAF.

3. Odor Control

Odor control by complete enclosure directly over the float removal equipment and ventilation of the air space under the cover to an appropriate odor control system is required for all but the most remote installations.

4. Pumps

- Feed pumps should deliver a relatively continuous flow. Centrifugal feed pumps should be used, rather than reciprocating or pulsed pumping systems.
- DAF float solids concentration can vary from 2 to 6 percent. Appropriate pumps for thickened solids are progressive cavity, rotary lobe, and piston or diaphragm reciprocating positive displacement pumps. Where pressure and grit concentrations in the thickened solids are high, progressive cavity and rotary lobe pumps may not be appropriate because of excessive wear. In these cases consideration should be given to piston or diaphragm pumps for thickened product pumping.

5. Polymer

- Relatively light molecular-weight polymers have been effectively used in DAF solids thickening. Consideration should be given to providing capability for mixing and feeding of polymers in either dry, liquid, or emulsion form in every installation.
- Solids capture rates of 90 to 95 percent can be achieved by using polymers as a floatation aid. Capture rates of 75 to 85 percent are more typical without polymer. Liquid processes should be designed to accommodate this inefficiency in capture. The size of an activated sludge aeration tank, for example, which is designed on the basis of solids retention time, must be proportionately increased to accommodate the inefficiency. This effect further enhances the cost-effectiveness of a higher-pressure, higher-loading DAF system designed for use with polymer as compared to a lower-pressure, lower-loading rate system without polymer.

6. Thickening

- Operation with a combined solids feed (primary and secondary solids) has resulted in higher cake solids at higher loading rates than with a feed of secondary waste solids only. Given this experience, every DAF installation should have the capability to mix and feed combined solids if such design is feasible.
- A key design decision is selection of the solids loading rate. Manufacturers' recommended loading rates differ widely, from 12 to 48 pounds per day per square foot. The lower loading rates are typically provided with lower-pressure recirculation systems (40 psi), while higher-pressure systems are used in higher-loaded systems (65 psi). Since a modest amount of polymer is usually required to get adequate capture, the higher-loaded systems with higher pressure recirculation are usually more cost effective.

7. Shape—Rectangular or Circular

There are several advantages of rectangular units over circular units, as follows:

- Rectangular skimmers can fit more closely together and use the space most efficiently.
- These units can be designed to use the entire water surface for skimming.
- The physical shape of the rectangular units permits solids flights that settle on the bottom to be driven independently of the skimmer flights.
- The water level in the rectangular tank can be easily changed by adjusting the end weir. This allows changing the depth of water and skimmer flight submergence to accommodate changes in float weight and displacement, which affect the skimming function.

The main advantage of circular units is their lower structural and mechanical equipment costs. Equivalent rectangular units require more structural material, drives, and controls, which also increase maintenance needs.

8. Concrete or Steel Tanks

Steel tanks generally arrive completely assembled and need only a concrete foundation pad, piping, and wiring hookups. Generally, equipment costs are higher for steel tanks, but field labor and expensive equipment installation costs are eliminated. Practical structural and shipping limits dictate the maximum size of steel tanks: maximum size is approximately 450 square feet for rectangular units and 100 square feet for circular units. Concrete tanks become more economical than steel for larger installations that require multiple or larger tanks.

9. Feed Characteristics

The characteristics of the residual solids to be thickened should be evaluated under various treatment plant loadings and modes of operation. For waste residual solids from a secondary treatment process, the solids age range should be established, because the age of the solids can significantly affect DAF performance. Combined waste solids from primary and secondary treatment processes for DAF thickening should be evaluated on the typical range of primary-to-secondary waste solids ratios. Parameters such as dissolved salts and range of liquid temperature affecting the air solubility of the process should also be considered.

10. Solids Loading Rate

The typical range of solids loading rates for common solids sources is presented in Table S-2. These loading rates will typically produce thickened solids of 4 percent or higher. In general, increasing the solids loading rate will decrease the float concentration. The use of coagulant will increase the solids loading rate.

Table S-2. Typical Dissolved Air Floatation Solids Loading Rates for Thickened Solids of 4 Percent or Higher

Type of Solids	Solids Loading Rate (lb/sq-ft/hr)	
	No Coagulant Use	**Optimal Coagulant Use**
Primary Only	0.83-1.25	up to 2.5
Waste Activated Sludge (WAS) Air System	0.42	up to 2.5
Oxygen	0.6-0.8	up to 2.2
Trickling Filter	0.6-0.8	up to 2.0
Primary + WAS	0.6-1.25	up to 2.0
Primary + Trickling Filter	0.83-1.25	up to 2.5

11. Hydraulic Loading Rate

The hydraulic loading rate is generally expressed as gallons per square foot of skimmer water surface per minute. This translates to the velocity equivalent of the average downward velocity of water as it flows through the thickening tank. The maximum hydraulic rate must always be less than the minimum rise of the solids-air particle to ensure that all of the particles will float to the water surface before the particle reaches the effluent end of the tank.

Since the total flow through the thickener affects the thickening process, the hydraulic loading rate should be based on the total flow, which includes the recycle flow. Typical peak hydraulic loading rates should not exceed 2.5 gallons per minute per square foot. This value is based on the use of polymers for coagulant purposes.

12. Air to Solids Ratio

The air to solids ratio is the quantity of air required to achieve satisfactory floatation. This design parameter is directly related to the proportion of solids entering the thickener. Parameters that affect the air to solids ratio are sludge volume index, the pressurization system's air dissolving efficiency, and the distribution of the gas-liquid mixture into the thickening tank. Typical ratios range from 0.01 to 0.4 pounds of air per pounds of solids.

13. Polymer Usage

The use of polymer as a flocculant increases the performance of the DAF thickener. Rarely can the thickened solids reach a concentration of 5 to 6 percent solids under normal operating conditions without the aid of polymers. Cost is the major disadvantage of using polymers when calculated over the useful lifetime of the facility.

S-2.1.3 Gravity Belt Filtration (Thickeners)

A. Purpose

The purpose of gravity belt filtration is to reduce the volume of liquid on downstream systems; to thicken solids for further treatment; thicken waste-activated solids (to 5 to 8 percent solids) with the use of coagulants; and to potentially thicken primary raw sludge (to 6 to 12 percent and more).

B. Requirements

- Equipment should be sized to meet the needs of the wastewater facility.
- Operators must have training and understand the operation and maintenance of the equipment.
- There must be a clear line of communication between the manufacturer and operator.
- Critical spare parts need to be identified.

C. Issues

1. Advantages

- The gravity belt filtration process requires a smaller footprint than other processes.
- The process can be less expensive than other mechanical thickening processes.
- The process uses less energy than other mechanical processes.

2. Disadvantages

- The gravity belt thickener filtration process requires the use of chemicals to aid in thickening.
- It is a mechanical process that is somewhat complex.
- The process is sensitive to the quality of the sludge being thickened.
- The gravity belt filtration process can thicken the solids too much, which may lead to handling problems in the downstream facilities.

3. Design Considerations

a. General

- The success of the equipment is subject to upstream conditions of the plant. The better the settling of solids in the plant, the better the gravity belt thickeners will function.
- After thickening has occurred, the means of transporting the solids is as critical as any pumping equipment and downstream piping. Consideration should be given by the engineer for piping and valves to be glass lined. Pumps should be capable of pumping the maximum solids content expected, without excessive maintenance and operations downtime.

- If digesters are the downstream facilities, it is important to ensure the mixing equipment in the digester will be able to mix the thickened solids properly.
- Care should be taken in calculating the friction loss in the glass-lined pipe.
- With all high solids pumping and piping facilities, it is recommended that a minimum of direction changes are made to reduce head loss in the piping. Wide sweeping turns should also be considered if room allows.
- Care should be taken in selecting the proper pressure equipment downstream of the pumps.

b. Mixing and Chemical Feeding

- Plows on the gravity belt must turn the thickened solids to allow water to drain through the belt fabric. The number and location should be adjustable for each solid.
- Chemical addition and mixing equipment are important, as are multiple injection points.
- Sizing of chemical feeding equipment is important, as is the chemical storage mixing and makeup needs for the chemicals used.

c. Air Handling and Odor Control

- Gravity belt filters must have an air handling system to maintain a safe working environment in the gravity belt filter room.
- Air-handling equipment directing the exhaust from the equipment and out of the room should have appropriate odor-control facilities.

d. Operation and Maintenance

- Gravity belt filters must have a curb around them and floors sloped to drains so that operators can properly clean the equipment quickly and safely.
- Metering of solids into and out of the equipment is important.
- Metering thickened solids must have bypass pipes and valves to allow the proper cleaning of the metering equipment. This will allow the gravity belt thickener equipment to be kept online.
- Care must be taken in the immediate downstream facilities (that is, the screw conveyor or conveyor belt) because the thickened sludge can tend to build up in piles and then fall onto the conveyor (sometimes right over it) in slug loads.
- Construction material for the equipment should be stainless steel because of the high potential for rust.

- Because of the height of the equipment, an elevated walkway will probably be needed to properly operate and maintain the equipment.
- The size of the drainage system is very important. Plan for easy cleanouts, as high solids are likely to be discharged to them during washdown by the operators.
- Ensure pumps and equipment that handle thickened solids can be properly accessed for operations and maintenance.
- Close proximity of laboratory drying equipment and jar testing equipment with proper laboratory facilities is important to ensure quick turnarounds on testing when making operational changes.
- Scum (grease) should not be placed on the gravity belt thickener because the blinding of the fabric and the cleanup normally needed after the thickening can create problems.

S-2.1.4 Belt Filter Press

A. Purpose

The belt filter press reduces the volume of solids that must be handled. In addition, it dewaters waste solids to 15 to 25 percent solids content (depending on the pretreatment of the solids before being fed to the belt filter press).

B. Requirements

- Equipment should be sized to meet the needs of the wastewater facility.
- Operators must be trained and understand the operation and maintenance of the equipment.
- There must be a clear line of communication between the manufacturer and operators.
- Critical spare parts need to be identified.

C. Issues

1. Advantages

- The belt filter process can be less expensive than other mechanical thickening processes.
- It uses less energy than other mechanical processes.

2. Disadvantages

- The belt filter process requires the use of chemicals to aid in thickening.
- It is a mechanical process that is somewhat complex.
- The process is sensitive to the quality of the sludge being dewatered.

3. Design Considerations

a. Upstream of Belt Filter Presses

Generally, there are two types of solids thickening before the solids are fed into the pressure section of the belt filter press. They include gravity belt thickeners and circular drum screens (RSTs).

Design considerations include:

Gravity belt thickeners	See S-2.1.3.
Circular drum screens (RSTs) with filter cloth on the exterior of the drum	• Chemical addition and mixing equipment are important, as are multiple injection points. • The sizing of chemical feeding equipment is important, as is the chemical storage mixing and makeup needs for the chemical used. • The success of the equipment is subject to upstream conditions of the plant. The better the settling of solids in the plant, the better the RSTs generally function. • Scum should not be placed into the RST because the blinding of the fabric and the cleanup normally needed after thickening can create problems.

b. Belt Filter Presses

Design considerations include:

General	• All piping to the belt filter press should be glass lined, with pumps capable of pumping the maximum solids content expected without excessive maintenance and operations downtime. • Care should be taken in calculating the friction loss in the glass-lined pipe. • With all high solids pumping and piping facilities, it is recommended that a minimum of direction changes are made to reduce the head loss in the piping. Wide sweeping turns should also be considered if room allows. • Care should be taken in selecting the proper pressure measuring equipment downstream of the pumps.
Mixing and chemical feeding	• Sizing of chemical feeding equipment is important, as is the chemical storage mixing and makeup needs for the chemical used. • Chemical addition and mixing equipment are important, as are multiple injection points upstream of the belt filter press. • Inline mixing equipment will likely be needed along with chemical injection equipment. Allow for multiple points of chemical injection and for inline mixing equipment to allow operators to minimize chemical use.

Air handling and odor control	• An air handling system is needed to maintain a safe working environment in the belt filter press room. • Air handling equipment for directing the exhaust from the equipment and out of the belt press room should have appropriate odor-control facilities.
Operation and maintenance	• Equipment must have a curb around it, with floors sloped toward drains so that operators can properly clean the equipment quickly and safely. • Flow measurement of solids to the equipment is important. • Construction material for the belt press should be corrosion resistant (that is, stainless steel) because of the high potential for rust. • Because of the height of the equipment, an elevated walkway will probably be needed to properly operate and maintain the equipment. • The size of the drainage system is very important. Plan for easy cleanouts, as high solids are likely to be discharged to them during washdown by operators. • Ensure all the pumps and equipment that will handle solids can be properly accessed for easy operations and maintenance. • Close proximity of laboratory drying equipment and jar testing equipment to laboratory facilities is useful, ensuring quick turnarounds on testing when making operational changes.

S-2.1.5 Centrifuges

A. Purpose

Centrifuges remove water from solids to reduce the mass of solids which must be transported from the treatment facility.

B. Requirements

- Centrifuges and ancillary equipment, such as feed pumps and polymer feed pumps, must be sized to meet peak design loading.
- Centrifuges and ancillary equipment, such as feed pumps and polymer feed pumps, must be sized to meet anticipated minimum loading at startup. Where appropriate, multiple units should be sized to ensure adequate redundancy, adequate turndown, and peak loading capacity.
- Since centrifuges have a high wear rate, all such components need to be identified and adequate spare parts provided.
- Adequate bench space should be provided to allow onsite testing for solids content and bench testing of polymers.

C. Issues

1. General

- Pretreatment that the sludge has received will affect the performance of the units.
- The nature of the collection system is important. Combined systems tend to contain more abrasive materials, which will affect unit life.
- Flow metering should be provided for both feed and polymer. Flow rate for both should be controllable.

2. Chemical Feeding

- The polymer system should provide enough flexibility to allow trials of multiple products.
- Polymer conditioning is required. The ability to utilize dry, emulsion, and mannic/solution products should be provided on all but the smallest systems.

3. Air Handling and Odor Control

- Containment and treatment of odors is important, especially if nonstabilized solids are being processed.
- HVAC design must ensure adequate air exchanges meet worker safety requirements and discharge through appropriate odor-control equipment.

4. Operation and Maintenance

- Adequate access must be provided to allow easy equipment maintenance and operation.
- Centrate lines should be designed to allow easy disassembly and cleaning because of the potential for struvite formation.
- Cake conveyance from the centrifuge to the haul vehicle requires careful design to avoid spillage or other problems.
- Facilities for hosedown of the area must be provided. Controls and other water-sensitive equipment must be either protected or located to avoid exposure to cleanup spray.
- Floors should be sloped to a drain to facilitate cleanup.
- Drains should be sized to accommodate thick sludge and debris.
- A system should be provided to weigh dewatered solids.
- Facilities and piping bypasses must be provided to allow units to be cleaned without compromising cake quality.

S-2.1.6 Drying Beds

A. Purpose

Drying beds are confined, underdrained, and shallow layers of sand over gravel on which wet sludge is distributed for draining and air drying.

B. General Description

Drying beds have proved satisfactory at most small and medium-size sewage treatment plants located in warm, dry climates. Digested and conditioned biosolids are discharged onto a drying bed and allowed to dewater and dry under natural conditions.

Dewatering using a drying bed is primarily a two-step process. Moisture separation and gravity drainage of free water is followed by evaporation. After the digested sludge is applied to the sand bed, moisture separation occurs when dissolved gases in the sludge are released and rise to the surface, floating the solids and leaving a layer of liquid at the bottom. The liquid drains through the sand, is collected in the underdrain system, and is usually returned to a plant unit for further treatment. After maximum drainage is reached, the dewatering rate slows down and evaporation continues until the moisture content is low enough to permit sludge removal. Dry sludge may be removed from the beds manually, by special conveyors, or with other loading equipment.

C. Requirements

1. Percolation Type

a. Gravel

The lower course of gravel around the underdrains should be properly graded and 12 inches deep, extending at least 6 inches above the top of the underdrains. It is desirable to place this in two or more layers. The top layer, at least 3 inches, should consist of one-eighth-inch to one-quarter-inch gravel.

b. Sand

The top course should consist of at least 12 inches of sand with a uniformity coefficient of less than 4.0 and an effective grain size between 0.3 and 0.75 millimeter.

c. Underdrains

Underdrains should be clay pipe, concrete drain tile, or other underdrain material acceptable to Ecology. Underdrains should be at least 4 inches in diameter and sloped not less than 1 percent to drain. Underdrains should be spaced not more than 20 feet apart.

In addition to underdrains, supernatant withdrawal pipes should be considered for aerobically digested sludges and for drying beds in western Washington.

2. Impervious Types

Paved surface beds may be used if supporting data to justify such usage are acceptable to Ecology. The use of paved beds for aerobically digested sludge is generally not recommended.

3. Walls

Walls should be watertight and extend 15 to 18 inches above, and at least 6 inches below, the surface. Outer walls should be curbed to prevent soil from washing onto the beds.

4. Sludge Removal

At least two beds should be provided, arranged to facilitate sludge removal. Concrete truck tracks should be provided for all percolation-type sludge beds. Pairs of tracks for percolation-type beds should be on 20-foot centers.

5. Sludge Influent

The sludge pipe to the beds should terminate at least 12 inches above the surface and be designed to drain. Concrete splash plates should be provided at sludge discharge points.

D. Issues

Drying beds are less complex and easier to operate, offer some flexibility, and require less operational energy than mechanical systems. They also require a larger site and more labor, primarily for biosolids removal. Poorly digested solids can cause odor problems. Winter weather and rainfall heavily influence the drying efficiency of drying beds. In general, it is desirable to construct multiple small beds rather than a few large beds because smaller beds offer greater operating flexibility. Consideration should be given to climatic conditions and the character and volume of the biosolids to be dewatered. Drying bed design should be based on square feet per capita or pounds of solids per square foot per year (see Table S-3). Additional space is required for wetter biosolids, such as those resulting from aerobic digestion; for low net evaporation areas, particularly in western Washington; and for using impermeable drying beds. Use of covered beds should be considered for western Washington locations.

Table S-3. Drying Bed Design Criteria

Type of Sludge	Open Beds		Covered Beds
	Per Capita (sq ft/capita)	Solids (lb/sq ft/yr)	Per Capita (sq ft/capita)
Primary	1.0 to 1.5	27.5	0.75 to 1.0
Primary and trickling filter	1.25 to 1.75	22.0	1.0 to 1.25
Primary and activated sludge	1.75 to 2.50	15.0	1.25 to 1.5

1. Advantages

- Drying beds offer ease and flexibility. Highly skilled operators are not needed.
- Drying beds generally have low maintenance costs.

2. Disadvantages

- Drying beds have large land requirements.
- Using drying beds can result in possible odor and vector problems from poorly digested solids.

3. Design Considerations

- Climate.
- Sludge characteristics.
- System design (including depth of fill).
- Chemical conditioning.
- Drying time.

E. Operation

1. Preparation for Filling

Before filling the drying bed with digested or conditioned biosolids, the sand layer should be scarified to break up any crust that may have formed. Sand is then added to replenish any that may have been removed when the bed was cleaned. The drain valve is then closed before adding water to the drying bed to cover the sand. The water over the sand keeps the biosolids from matting over the sand and preventing drainage.

2. Filling

Initially, fill the drying bed to a depth of about 8 inches. Measure the depth of solids after three days. The amount of decrease in the bed is the drawdown of the bed. Normal filling depth should be equal to twice the three-day drawdown.

3. Sampling and Testing

While filling the drying bed with well digested biosolids, an operator grabs a 2,000 ml or greater sample to test for percent solids and to do a separation test. After removing the solids sample amount, the operator puts the remainder of the sample in a wide container to allow the sample to separate. When the sample separates, or after 24 hours, the operator opens the drying bed drain valve to allow the separated water to return to the plant for further treatment.

4. Return Flows

Drainage from drying beds should be returned to the treatment process at appropriate points preceding the secondary process. The return flows should be returned downstream of the influent sample point and a means should be provided to sample return flows. These organic loads should be considered in plant design.

5. Cleaning (After Dewatering)

Dried sludge may be removed from the beds by hand scraping, being careful not to remove sand with the sludge. A small tractor with a front-loading bucket can be used to remove the solids. The front-end loader cannot completely remove all of the solids. Solids left on the bed require manual removal with a shovel or scoop. Avoid operating vehicles and equipment directly on the sand; instead lay planks or plywood on top of the bed if permanent vehicle treadways are not provided. After the solids are removed, inspect the bed, rake the surface of the sand to level it and remove any debris, and add makeup sand if necessary.

F. Control Considerations

Drying bed performance is affected by weather, biosolids characteristics (stabilization by digestion, inorganic content), system design and condition, depth of fill, chemical conditioning, and drying time. Another consideration is odors.

1. Weather Effects

Freezing and occasional moistening by rain may not be detrimental to drying sludge on uncovered beds. Thawed sludge releases its moisture more rapidly than sludge that has not been frozen, and the sludge is left in a light, fluffy condition. Sludge that is slightly moistened during the drying process will dry as rapidly as unmoistened sludge; that is, some rain may not delay drying of sludge on the bed, although too much rain will.

2. Biosolids/Sludge

Sludges containing grit dry rapidly, while sludges containing grease dry more slowly. Primary sludge dries faster than secondary sludge, but not as fast as digested biosolids. In well digested biosolids, gases tend to float the solids and leave a clear liquid layer, which drains through the sand when the drain valve is opened.

3. Chemicals

Chemicals are used to condition sludges that are hard to dewater or when drying beds are overloaded. The chemicals most commonly used are alum, ferric chloride, chlorinated coppers, and organic polyelectrolytes. Lime or alum may be added to the sludge as it is placed on the beds. Alum is added at the rate of about 1 pound of alum per 100 gallons of sludge. Lime is also good for keeping down odors and insects.

4. Efficiency

Before adding biosolids/sludge to drying beds, remove trash, weeds and other vegetation that might be present in the beds. The sand should be raked and leveled to make sure that the biosolids/sludge can drain properly, with additional sand added as necessary to maintain at least 4 inches of sand over the gravel. Biosolids/sludge should not be added to a drying bed that contains partially dried solids. The useful capacity of the drying beds can be maximized by removing the biosolids as soon as the biosolids have reached the desired dryness.

5. Odors

Odors indicate poor sludge digestion. The first step to control odors is to correct the efficiency of the digestion process. As a temporary solution, add lime to the sludge. Lime may help control odors; however, it may also tend to clog the sand and interfere with dewatering.

6. **Drying Time**

   Drying time can be reduced by disturbing the solids in the drying bed after they begin to dry. As the solids dry, a crust forms on top of the solids. If the solids are mixed, turned, or otherwise disturbed, the crust is broken up, allowing for more rapid evaporation.

S-2.1.7 Thermal Drying

A. Purpose

Thermal drying involves the removal of water by evaporation. In addition to significantly reducing the mass of solids that must be transported from the treatment facility, thermal drying may be used to achieve the "vector attraction reduction" requirement of the 40 CFR Part 503 regulations and potentially can be used to produce Class A biosolids.

B. Requirements

- Adequate fire suppression equipment must be provided.
- All drying facilities' HVAC systems must be designed to ensure worker safety while addressing odor control issues.
- On-site storage must be adequate to address weather-related haul limitations.
- Redundancy must be provided for equipment maintenance. Poor housekeeping and equipment maintenance is a common cause of product fires and explosions.
- Recycle loads on the liquid stream must be considered.

C. Issues

- Because this process utilizes heat energy, operational costs can normally be minimized by delivering the driest possible solids to the drier. Thus, thermal drying processes are normally proceeded by a physical dewatering technology, such as centrifuges or belt filter presses.
- Odors associated with thermal decomposition and volatilization of organics is a major issue. Significant attention must be paid to odor control.
- Depending on the specific process equipment utilized, dust control may be an issue along with worker safety.
- Appropriate steps must be taken to address spontaneous combustion of the dried product.
- Product storage and conveyance to haul vehicles is a concern.
- Special licensing of plant personnel may be required, such as boiler licenses.
- Solids handling and dried product recycling requires careful review.
- Developing a "sticky phase" is a common problem with thermal dryers. Startup may require an external source of dried material to

raise feed solids content above concentrations at which a "sticky phase" occurs.

S-2.1.8 Bag Dewatering/Air Drying

This process utilizes bags made of fabric that allows water to leave the sludge and seep out while keeping the solids inside the bags. Generally, the bags are filled and then piled on pallets placed on pads with drains that return the drainage water to the plant. The process can be used in wet or dry climates, and can dewater and air-dry the solids to 50 percent. Some emerging technologies may increase the dryness to 75 to 90 percent.

This process is generally cost-effective for small facilities with flows under 0.5 mgd or solids production between 10 and 300 pounds per day.

S-2.2 Solids Stabilization

The purpose of solids stabilization is to "reduce the odors and bacteria levels in the sludge feed, leaving the stabilized sludge relatively inert" ("Operation of Municipal Wastewater Treatment Plants," WEF Manual of Practice No. 11, 1996).

Methods of stabilization of sludge include:

- Digestion—anaerobic and aerobic.
- Chemical addition (not covered in this manual).
- Composting.

S-2.2.1 Digestion

A. General Description and Classification of Sludge Digestion

Digestion is the most commonly used method of wastewater sludge stabilization in the US. The two main categories of sludge digestion are as follows:

- **Anaerobic digestion.** Anaerobic digestion occurs in the absence of oxygen and generates methane gas. Anaerobic digestion is widely used for plants with average wastewater flows of more than 5 mgd.
- **Aerobic digestion.** Aerobic digestion requires oxygen. Aerobic digestion is more commonly found in smaller plants with flows of less than 5 mgd.

See Table S-4 for a summary of the general features and design criteria of different sludge digestion systems.

Table S-4. Summary of Wastewater Sludge Digestion Systems Design Criteria

Design Feature	Psychrophilic Anaerobic	Mesophilic Anaerobic	Thermophilic Anaerobic	Aerobic (Mesophilic or Thermophilic)
Aeration	None	None	None	Yes (Additional O_2 demand for nitrification in mesophilic systems)
Temperature (degrees F)	41-68	85-104	122-140	50-104 (meso.) 122-140 (thermo.)
Solids Loading Rate (lb VS/cu ft-d)	Variable	0.03-0.30	0.08-0.20	0.10-0.30
Solids retention time (day)	>180	30-60 (low-rate) 10-20 (high-rate)	potentially less than 10	10-15
pH	6.5-7.2	6.8-7.2	6.8-7.2	around 7
Class A/B biosolids	Typically Class B	Class B	Class A	Class A (thermophilic)

B. Anaerobic Digestion—Mesophilic

Anaerobic mesophilic digestion is the most commonly used sludge stabilization process for treatment plants with average wastewater flows greater than approximately 5 mgd. Digestion by mesophilic bacteria occurs at temperatures in the range between 85 and 104° F.

1. Process Variables

The following are the four main process variables to be considered in the design and operation of mesophilic anaerobic digestion.

- Solids loading rate.
- Solids retention time (SRT).
- Temperature.
- pH.

2. Design Considerations

The following aspects are integral to the design of an anaerobic mesophilic digestion system.

- Digester shape.
- Digester cover and bottom.
- Mixing system.
- Heating system.
- Gas collection, storage, and use.

3. Operational Considerations

The following aspects should be considered to optimize the operation of the anaerobic digestion system.

- Feeding and withdrawal.
- Scum and grit management.
- Foam control.
- Scale control.
- Odor control.

C. Anaerobic Digestion—Thermophilic

Thermophilic anaerobic digestion is in principle similar to anaerobic mesophilic digestion, except that thermophilic digestion occurs at temperatures between 122 and 140° F. Because biochemical reaction rates increase as the temperature increases, thermophilic digestion is faster than mesophilic digestion for the same volatile solids reduction. The higher temperature at which thermophilic digestion takes place also allows for increased pathogen destruction. As a result, thermophilic anaerobic digestion is applied to achieve Class A biosolids.

1. Process Variables

Similar to mesophilic digestion, the following are the four main process variables to be considered in the design and operation of thermophilic anaerobic digestion.

- Solids loading rate.
- Solids retention time (SRT).
- Temperature.
- pH.

2. Design Considerations

Thermophilic anaerobic digestion generally has the same design considerations as anaerobic mesophilic digestion.

- Digester shape.
- Digester cover and bottom.
- Mixing system.
- Heating system.
- Gas collection, storage, and use.

3. Operational Considerations

The same operational considerations for mesophilic digestion generally apply to thermophilic digestion. Because of the higher sensitivity of thermophilic bacteria to temperature changes, temperature control is especially important. The higher operating temperature in thermophilic digesters tends to suppress scum and foam formation, so that scum and foam control is often less problematic than in mesophilic digesters.

- Feeding and withdrawal.
- Temperature control.
- Odor control.

D. Aerobic Digestion

Aerobic digestion is primarily used in plants with design flows of less than 5 mgd. It has been successfully used in extended aeration activated sludge facilities and in many package-type treatment facilities. The biologically degradable organic component of the sludge is stabilized via oxidation (in the presence of oxygen). Aerobic digestion is thus, in principle, similar to the activated sludge process. Some of the advantages of aerobic digestion over anaerobic digestion include lower odor potential, production of nonexplosive gases, a relatively clean recycle stream (lower BOD concentration in digester supernatant), low capital cost, and simple operation. Disadvantages of aerobic digestion over anaerobic digestion include higher power costs associated with aeration, reduced cold weather efficiency, nonproduction of methane gas from which energy can be recovered, and possibly poor mechanical dewatering characteristics of the digested sludge.

1. Process Variables

The following are the five main process variables in the design and operation of aerobic digesters.

- Solids loading rate.
- Solids retention time.
- Temperature.
- pH and alkalinity.
- Oxygen consumption.

2. Design Considerations

The main design difference between an aerobic digester and an anaerobic digester is the aeration system required for aerobic digestion. The types of tank shapes (cylindrical or rectangular) and digester bottoms are generally similar to those used for anaerobic digesters. Because no methane is produced in aerobic digestion, there is no digester gas collection and storage system and the digesters are normally constructed as uncovered, unheated aeration basins. In colder climates, the tanks may be covered to prevent icing. In dual-digestion systems, digester gas is produced in the anaerobic reactor, so that a gas collection and handling system is required.

3. Operational Considerations

The following are the main operational considerations for aerobic digestion.

- Feeding and withdrawal.
- Aeration control.
- Foam control.
- Odor control.

S-2.2.2 Composting

A. General Description

Composting is “the biological decomposition and stabilization of organic substrates, under conditions that allow development of thermophilic temperatures as a result of biologically produced heat, to produce a final product that is stable, free of pathogens and plants seeds, and can be beneficially applied to land” (Haug, 1993). The objective of composting is to biologically covert putrescible organics into a stabilized form, to destroy pathogens, and to produce a dry product for beneficial reuse. Composting can be applied to stabilize a variety of feedstocks, including solid wastes, manure, yard waste, agricultural crop residues, and wastewater sludges. Most composting processes are operated under aerobic conditions.

Composting can be applied as a stand-alone sludge stabilization process for treatment of raw sludge, or as a post-stabilization process for treatment of digested sludge. It is normally performed after dewatering.

B. Requirements

Regulations and guidelines which apply to the composting of biosolids include the 40 CFR Part 503 regulations, and State of Washington law and regulations described in S-1.2. Additional information is also in the “Compost Facility Resource Handbook.”

C. Process Variables

Factors which influence the operation and product quality of biosolids composting include pile porosity, moisture content, temperature, carbon-to-nitrogen ratio, oxygen, pH, and detention time.

Pile porosity or pore space refers to the area around individual compost particles. For optimum growth of microorganisms, both oxygen and moisture are needed in the pore space. Too much water in the pore space creates anaerobic conditions, which lead to odor problems and slower decomposition.

It is very important to establish good porosity at the beginning of the composting process by adding a bulking agent or grinding feedstocks to a specific particle size.

1. Moisture Content

The optimal moisture content for composting is in the range of 50 to 60 percent (Brown and Caldwell, 1994). Bulking agents and amendments absorb excess moisture from dewatered biosolids, which are usually too wet for optimal composting.

2. Temperature

The most efficient temperature range for composting is between 104 and 140° F (WEF Manual of Practice No. 8, 1991). Biosolids compost must reach 122° F for a specific length of time, depending on the technology, in order to have completed a “Process to Further Reduce Pathogens” (PFRP). For windrows, compost must remain at 131° F for at least 15 days with five turnings during the 15-day period. For aerated static piles or invessel technologies, the compost must remain at 131° F for at least three days. In addition, for each of the technologies listed above, the compost must meet vector attraction reduction requirements by continuing the time/temperature treatment for an additional 14 days. (The compost must be maintained at 104° F or higher with an average temperature of at least 113° F during the 14-day period.)

3. Carbon-to-Nitrogen Ratio

The optimum carbon-to-nitrogen ratio ranges from 25 to 35 (by weight) (Brown and Caldwell, 1994).

4. Oxygen

The optimum oxygen concentration in a composting process is between 5 and 15 percent.

5. pH

The pH is generally self-regulating and varies within the compost process. The optimum pH for bacteria is 6.0 to 7.5, and 5.5 to 8.0 for fungi.

6. Detention Time

The total detention time provided for the composting process varies, depending on the type of system employed, available storage area, and characteristics of the sludge to be composted. Maintaining temperatures for the specified length of time (as described above) is a fundamental requirement of federal and state biosolids regulations regarding composting. Once regulatory requirements are met, curing should continue until the compost is stable enough for the intended market.

D. Types of Composting Systems

Composting processes are generally classified according to the three main types of systems: windrow, aerated static pile, and invessel systems. A system is classified by determining whether it is a reactor- or nonreactor-based system, and whether or not the composting materials are turned.

1. Windrow System

A windrow system, the oldest of the three systems for sewage sludge composting, consists of mixtures of biosolids and bulking agents placed in long rows (called windrows) that are turned periodically using mobile equipment. A windrow is sometimes referred to as an agitated solids bed. A conventional windrow system relies on natural ventilation for the supply of oxygen. An aerated windrow system uses forced aeration to supplement the aeration provided by turning the windrows.

2. Aerated Static Pile

The aerated static pile method is the most commonly used composting process in North America. This type of system consists of a grid of aeration or exhaust piping placed beneath the compost pile. The aerated static pile method differs from the windrow process in that composting material is not turned. Also, the composted material is usually not recycled to adjust for moisture content, although it is often used as an insulative pile cover. The dewatered sludge is mixed with a bulking agent-to-sludge ratio of about 2:1 to 3:1 by volume (Haug, 1993).

3. Invessel System

Invessel systems, sometimes also called reactor or enclosed mechanical systems, offer the potential of producing more stable and consistent compost products than windrow and aerated static pile processes, with smaller space requirements and better containment and control of odor. The disadvantages include greater operational complexity and labor requirements. Invessel processes are classified as either vertical flow or horizontal flow.

E. Design Considerations

The two main design considerations for composting include the selection of the bulking agent/amendment and the design of the aeration system.

1. Selection of Bulking Agent/Amendment

A bulking agent is a material, organic or inorganic, of sufficient volume to provide structural support and maintain air spaces within the composting matrix. If the bulking agent is organic, an increase in the energy content of the mixture is a secondary benefit. Materials used as bulking agents include wood chips, shredded tires, peanut shells, and tree trimmings. Bulking agents may be screened before or after the curing process and reused in the compost mixture.

An amendment is a material added in order to condition the feed sludge mixture. It can serve as either a structural or drying element to reduce bulk weight and increase porosity or an energy or fuel amendment to increase the quantity of biodegradable organics (thus the carbon-to-nitrogen ratio) in the mixture and, thereby, increase the energy content. Organic materials are used to provide supplemental carbon and include sawdust, yard waste, manure, and a variety of other waste materials. Because part of the organic substance supplied as an amendment is degraded in the composting process and materials such as sawdust are too fine to be screened, amendments are usually not recovered and recycled.

The two terms “bulking agent” and “amendment” are often used interchangeably. Regardless of the term used, the specific type of material selected to mix with the feed sludge should have a low moisture content, supply carbon to the process (if the carbon-to-nitrogen ratio is low using just the feed sludge), be easy to handle, and be reasonably inexpensive. Both sawdust and wood chips have been widely used as an amendment or bulking agent. Sawdust has value as a boiler fuel and as a raw material for particle board production, and may therefore be expensive. Wood chips, while large enough to be mostly recovered and recycled, also have a commercial value and may be expensive. Yard and green wastes are inexpensive compared to other materials, and the woody material present in this product has proven to be an effective bulking agent. However, lawn clippings have proved to be detrimental to the composting process. Inert materials such as shredded tires help increase porosity but do not provide a carbon source. In many composting facilities, a combination of materials, such as woods chips and shredded tires, is added to the feed sludge.

The addition of a bulking agent/amendment will affect the characteristics of the resulting compost product. Typically, about two to five parts by volume of bulking agent/amendment is added to one part biosolids, depending on the initial porosity and carbon content of the biosolids (Brown and Caldwell, 1996; Haug, 1993; Williams et al., 1996).

2. Aeration System

In composting processes, air is required for the following reasons:

- To satisfy the oxygen demand from organic decomposition.
- To reduce the moisture content by removing the water vapor.
- To remove the heat generated by organic decomposition to control the process temperature.

The aeration rate for biological oxidation typically amounts to 0.6 cu m/min/dry metric ton (20 cu ft/min/dry ton), while the aeration rate for drying ranges between 0.6 and 2.8 cu m/min/dry metric ton (20 and 100 cu ft/min/dry ton) (WEF, 1995). The air demand for wastewater sludge is usually similar for moisture removal and heat removal, and the air demand for biological oxidation is less than for either. Lower air volumes would be needed for digested biosolids, which have less biodegradable solids available, while higher volumes are needed for raw sludge.

Aeration can be forced, natural, or provided through periodic mechanical mixing. Excessive aeration will lead to cooling of the composting materials and premature drying. Inadequate aeration may cause the composting materials to become anaerobic and result in excessive temperature, which will inhibit microbial activity and generate odors.

In forced aeration systems, the air supply rate can be uncontrolled or manual, or it can be based on a combination of time operation, oxygen or carbon dioxide content, air flow rate, and/or temperature. Temperature control, being the predominant method of aeration control for compost systems, can also be combined with oxygen control to achieve heat and moisture balance. Centrifugal blowers are most commonly used in forced aeration systems. Blowers are usually installed with timer controls for intermittent operation. Blowers, fans, and appurtenances such as aeration ducts should be constructed of materials that will withstand corrosive, moisture- and dust-laden air.

It is recommended that the aeration system be designed for interchangeable negative (induced draft) and positive (forced draft) modes. Usually a negative mode (that is, downflow through the pile) is maintained during the first half of the compost sequence, when the potential for odors is greatest. The air drawn through the piles can then be blown to an odor control system. The mode is then changed to positive (that is, upflow through the pile) to accelerate drying during the final stages of composting.

F. Operational Considerations

In order to properly operate a composting facility, the following items should be considered.

1. Odor Control

Composting often generates significant odors, particularly when raw sludge is composted. The four main groups of odor-generating chemical compounds found in the composting process include ammonia, hydrocarbons, sulfur compounds, and fatty acids (WEF, 1995).

Frequently, odors are released during turning operations. To minimize odors, processes involving turning of compost are usually not recommended. Alternatively, turning operations could be scheduled for periods when the potential for odor complaints is minimal, such as when wind direction is away from populated areas. Also, aerobic conditions should be maintained within the pile. Windrows or static piles can be placed within enclosures or buildings with proper ventilation and collection and treatment of off-gases. Typical treatment systems include biofilters, packed bed scrubbers, and activated carbon adsorbers. Use of such amendments as lime and wood ash in the compost mixture may also help control odor emissions.

2. Screening, Curing, Materials Handling, and Storage

Screening is often performed following composting. Screening removes bulking agents (as much as possible) for recycling to minimize operational costs, reduces the overall volume of compost, improves product quality, and allows variation in product texture. Fine materials such as sawdust are not screened. The moisture content of the compost is a key factor in the success of screening operations. If the compost is too wet, the material will be sticky and the screen may bind. If the compost is too dry, dusty nuisance conditions may prevail. A solids content of the compost between 55 and 60 percent is recommended (WEF, 1995). Vibrating deck screens and rotating screens (trommel screens) with cleaning brushes are often used. The trommel screen operates at a slightly higher moisture content.

3. Drainage Management

Runoff from surfaces covered with biosolids may contain fecal coliform and other contaminants. To protect the environment, an effective drainage management system is needed. Potentially contaminated runoff from the building and immediate paved surfaces should be routed to a sewer system for further treatment.

The Compost Facility Resource Handbook has sections that describe the regulatory requirements as well as outlining design criteria (with references to other documents) for managing leachate and stormwater. Compost facilities located at publicly owned treatment plants have obvious advantages for leachate and stormwater management. Other facilities will need to address these issues differently.

4. Monitoring and Sampling

Monitoring and sampling are performed in order to monitor for process efficiency and quality control and provide data for regulatory compliance. Aeration rates are often adjusted according to a feedback control of the temperature and/or oxygen level in the compost pile. In static piles, several monitoring points can be used within the piles. Typically, at least one point is located in the front, one in the middle, and one at the back toe of each pile. Other important monitoring parameters include moisture content, carbon-to-nitrogen ratio, pathogen density, and odor levels.

Monitoring parameters and frequencies required for a Type 2 facility (biosolids composting) are listed in Ecology's "Interim Guidelines For Compost Quality" (1994).

S-2.3 Ash Production

Ash production is achieved by incineration.

S-2.3.1 Purpose

The purpose of incineration is to reduce and stabilize residual solids.

S-2.3.2 General Description

There are two types of incinerators: multihearth and fluidized bed.

A. Multihearth

Multihearth incinerators are cylindrical refractory line vessels containing a number of hearths, with rabble arms for moving the solids through the unit. Sludge enters through the top of the incinerator and is rabbled downward to the ash removal equipment at the bottom. The top hearths are used for drying, the middle hearths are for burning, and the bottom hearths are for cooling the ash.

- Biosolids should be fed at an even flow rate and shredded as it enters the incinerator.
- Design loading ranges from 6 to 12 lbs/hr/sf of hearth depending on the type and moisture content of the biosolids applied.
- Multihearth incinerators operate at 1,400 to 1,700° F.
- Feed-air ports should present an even air supply below the burning hearth.
- Power generation equipment must be powerful enough to at least support shaft cooling fans.

B. Fluidized Bed

Fluidized bed incinerators are cylindrical refractory line vessels with a grid in the lower section to support a sand bed. Preheated combustion air is supplied under the sand to float the bed. Ash is carried out the top of the incinerator and removed from the off-gas stream. Supplemental heat is added to the fluidized bed to bring internal temperatures to between 1,400 and 1,800° F. Biosolids enters through nozzles into the sand bed for drying and combustion.

- Design loading ranges from 6 to 14 lbs/hr/sf depending on the type and biosolids moisture content of the biosolids applied.
- Fluidized bed incinerators operate at 1,400 to 1,800° F.
- The sand bed acts as a heat sink and can be operated on partial days without substantial heat loss.

S-2.3.3 Requirements

- The incinerator must be large enough to meet the residual solids needs of the wastewater facility. This sizing should include the needs of short-term storage for maintenance as well as future plant growth needs.
- An incinerator requires dewatering equipment with the ability to increase solids concentration above 20 percent for feeding into the incineration process. The process therefore must have transfer equipment with the ability to increase solids concentration above 20 percent for feed into the incineration process. The higher the solids or volatile content of the cake feed, the higher the feed rate to the incinerator.
- State of Washington incinerator operator certification is required to operate incinerators.
- System monitoring as specified in the 40 CFR Part 503 regulations for discharge air and process testing must be in place for daily, monthly, semiannual, and annual records.
- The ash handling and storage capacity should be adequate for transferring and holding ash, depending on the ultimate disposal method.
- Ash must be disposed of at the permitted disposal site.

S-2.3.4 Issues

A. Advantages

- Incineration substantially reduces the quantity of biosolids to an inert end product.
- Processing and disposal of the residual biosolids is independent of outside conditions. This can be an advantage where there is opposition to reuse, changes in urbanization are anticipated, or where reuse is impacted by winter weather.

B. Disadvantages

- Current regulation trends are moving away from simple disposal of biosolids toward beneficial reuse. Ash disposal now requires a permitted landfill. Permitted landfills are regional facilities that greatly increase the transport and disposal price of ash. Air monitoring requirements as prescribed in 40 CFR Part 503 have imposed increasingly stringent regulations.

- Incineration demands constant monitoring by certified incineration-only operators. This cost, along with fuel, power, and ash transportation, adds to the overall high expense of incineration.
- Sludge incineration is a balanced process dependent on the functioning of other treatment processes. It is therefore susceptible to downtime because of power interruption or equipment malfunction.
- Maintenance inside an incinerator requires a cool-down period to an ambient temperature and a gradual heat-up period to complete operations. Extended incineration downtime requires substantial storage capacity or sludge hauling to a separate facility.

S-2.4 Storage

Solids can be stored in lagoons, tanks and basins, silos, bags, and bulk storage.

S-2.4.1 Lagoons

Raw, partially, or fully treated solids may be stored in lagoons pending further processing or disposition, but “storage” may be considered “treatment” with any significant residence time in the storage unit or in the absence of characterization or plans for monitoring and ultimate end-use. Sheer storage volume can lead lagoons to “out-of-sight, out-of-mind” status. But good planning and design will not only address design elements such as appropriate dike engineering and liners, but also consider other factors including long-term planning issues.

S-2.4.2 Tanks and Basins

A. Purpose

Holding tanks and basins are commonly provided as an integral part of most conditioning processes and many stabilization processes. Tanks and basins may be used for blending materials, such as wastewater solids from primary and secondary clarifiers.

B. Design Considerations

Large storage tanks are generally constructed of concrete. Smaller tanks are often constructed of carbon steel with a suitable coating system. Tank and basin equipment often includes an aeration system, mechanical mixers, or a recycling system for mixing. All equipment within the tank should be constructed of a corrosion-resistant material such as PVC, PE, or stainless steel.

C. Issues

1. Storage Time

Tanks and basins may be sized to retain wastewater solids for a period of several hours to a few days. If wastewater solids are stored longer than two or three days, the product will deteriorate and can be difficult to dewater.

2. **Inspection and Maintenance Access**

   If the tank or basin is a closed vessel, ensure that there are access portholes for inspection and maintenance. All access portholes need to meet current OSHA requirements.

3. **Odor Control**

   Even short storage periods of unstabilized primary and secondary wastewater solids in a holding tank or basin can produce nuisance odor. Decanting tanks following thermal conditioning often creates major odor problems.

S-2.4.3 Bulk Storage

Dewatered biosolids can be stored (stockpiled) for up to two years or longer if specifically approved. Without approval, facilities that hold material in excess of two years may be considered disposal facilities, which can result in significant changes in the approach to facility design, operation, and regulation.

Design considerations for bulk storage are as follows:

- The size of the biosolids storage area depends on the quantity of biosolids produced, when it can be utilized, and its moisture content. Drier solids can be stacked higher with less tendency to slump. Additional space should be provided for scheduled process cleaning (lagoon dewatering or digester cleaning) and emergency situations (permit violations or second-party treatment).
- Storage must be in accordance with the biosolids application permit (if one is issued).
- Storage must be in accordance with requirements of the local health district.
- Materials must not be stored in a manner that results in (or would be likely to result in) contamination of ground or surface waters, air, or land in case of flood or fire.
- The storage area should be constructed and sited to prevent run-on and runoff of liquids.
- A solids storage area needs a water collection system and way to treat the leachate produced from the pile. Bulk storage should be managed to prevent the pollution of ground or surface waters. Odors can be a problem depending on the population density of the area, quality of the solids (stability), and prevailing winds. The storage area should be constructed to prevent run-on and runoff of water. Care must be taken not to contaminate the solids with oil, grease, gas, rocks, litter, etc. The area must be secure to prevent access by the public, domestic animals, or wildlife.

S-3 Residual Solids Management: End-Use Options

This section intends to only mention various biosolids recycling and disposal options. Possibilities include land application options (including both direct application to the land and as a component of compost or topsoil products), disposal in landfills, and incineration.

Chapter 70.95 RCW favors recycling options over other disposal options, such as disposal in landfills and incineration. Chapter 70.95J RCW further directs Ecology to pursue the maximum beneficial use of biosolids. Ecology has adopted Chapter 173-308 WAC to implement a statewide biosolids management program that encourages the maximum beneficial use of biosolids.

Ecology discourages incineration and long-term reliance on landfill disposal as end uses. No other information related to end-use options is included in this manual. Refer to Ecology's Solid Waste Program requirements, Washington State rules on biosolids management (Chapter 173-308 WAC), Chapter 70.95J RCW, and 40 CFR Part 503 for guidance.

S-4 References

Brown and Caldwell. Draft Report for the Pierce County Utilities Chambers Creek Wastewater Treatment Plant Master Site Plan. Task 3.1, Biosolids Compost Facility Conceptual Plan. 1994.

Brown and Caldwell. Pierce County Department of Public Works and Utilities Soil Manufacturing Facilities. Plan of Operations Report. 1996.

Burke, D.A., R. Butler, R. Finger, and S. Hummel. Improved Biosolids Digestion Utilizing Anoxic Gas Flotation. In Proceedings of the 70th Annual Conference and Exposition of the Water Environment Federation. 1997.

Ghosh, S. and K. Buoy. Two-Phase Fermentation: An Innovative Approach to Gasification of Biosolids Resources. In Proceedings of the 10th Annual Residuals and Biosolids Management Conference, Water Environment Federation, 1996.

Haug, R.T. The Practical Handbook of Compost Engineering. Boca Raton: Lewis Publishers, 1993.

Hay. J.C., et al. "Windrow Composting in Los Angeles County." Biocycle Magazine, Part 1 & 2, 26(7), 24, 1985.

Kerri, Kenneth D., et al. Operation of Wastewater Treatment Plants. Volumes I and II. California State University. 1988.

Mavinic, D.S. and D.S. Koers. "Performance and Kinetics of Low Temperature, Aerobic Sludge Digestion." Journal of the Water Pollution Control Federation, 51, 2088, 1979.

Metcalf & Eddy, Inc. Wastewater Engineering—Treatment, Disposal, and Reuse. Third Edition. New York, NY: McGraw-Hill, Inc., 1991.

Peddie. C.C., J. Tailford, and D. Hoffman. Thermophilic Anaerobic Sludge Digestion—Taking a New Look at an Old Process. In Proceedings of the 10th Annual Residuals and Biosolids Management Conference, Water Environment Federation, 1996.

Stukenberg. J.R., J.H. Clark, J. Sandino, and W.R. Naydo. "Egg-Shaped Digesters: From Germany to the US." Water Environment and Technology, 4(4), 42-51, 1992.

US Environmental Protection Agency. Process Design Manual for Sludge Treatment and Disposal. EPA 625/1-79-011, 1979.

US Environmental Protection Agency. Standards for the Use or Disposal of Sewage Sludge. US EPA 40 CFR Part 503, 1993.

Viessman, W. and M.J. Hammer. Water Supply and Pollution Control. Fourth Edition. New York: Harper & Row Publishers, Inc., 1985.

Walker. J., et al. US Environmental Protection Agency Office of Wastewater Management. A Plain English Guide to the EPA Part 503 Biosolids Rule. EPA/832/R-93/003, 1994.

Washington State Department of Ecology. Biosolids Management Guidelines for Washington State, Publication No. 93-80. (Being revised as of this printing; expected publication date, 1999.)

Washington State Department of Ecology. Interim Guidelines for Compost Quality. Publication No. 94-38. 1994.

Water Environment Federation. Biosolids Composting. 1995.

Water Environment Federation. Design of Municipal Wastewater Treatment Plants. WEF and ASCE. Manual of Practice No. 8. 1992.

Water Environment Federation. Operation of Municipal Wastewater Treatment Plants. Manual of Practice No. 11. Fifth Edition. 1996.

Water Pollution Control Federation. Sludge Stabilization. Manual of Practice FD-9. 1995.

Williams, T., R.A. Boyette, E. Epstein, and S. Plett. Proceedings of the Water Environment Federation 69th Annual Conference & Exposition. Volume 2, Residuals and Biosolids Management. From the Biosolids Composting Conference in Davensport, Iowa, 1996.

Zickefoose. C. and J. Hayes (for the US EPA Office of Water Programs). Operations Manual for Stabilization Ponds. Environmental Protection Agency. 1977.

Zinder. S.H. “Thermophiles: General Molecular and Applied Microbiology.” In Thermophilic Waste Treatment Systems, T.D. Brock, editor. New York: Wiley-Interscience. 257-277, 1986.